

# **EUV mask absorber pattern inspection using DUV inspection tool**

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- Summary

\*AR = Anti Reflective

\*\*LR-TaBN = Low Reflectivity TaBN

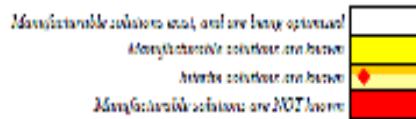
# Motivation

In addition to Generic mask requirement, EUVL specific mask requirements are listed on ITRS

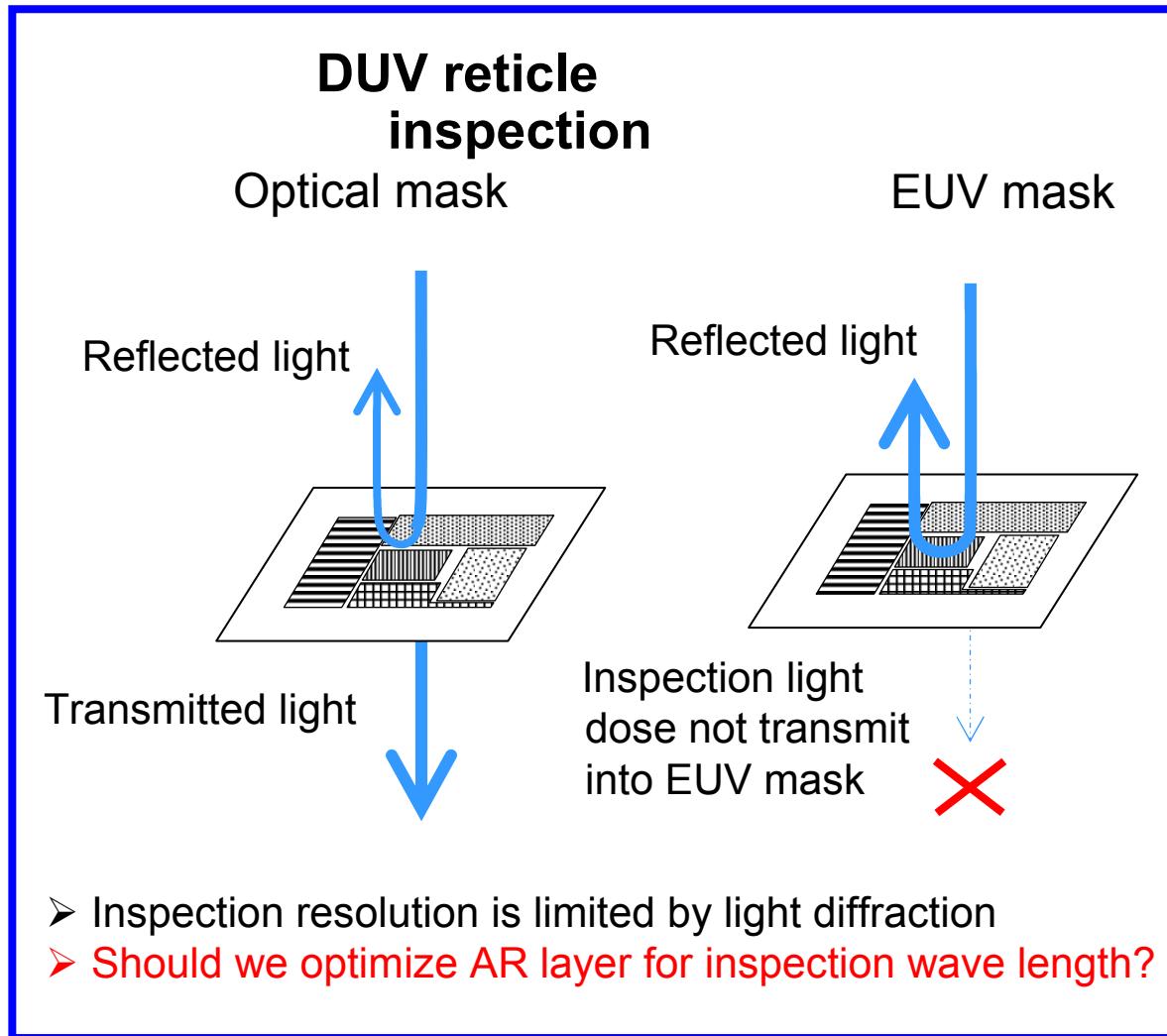
- ◆ Mask manufacturing remains challenges for the implementation of EUVL into HVM
  - Pattern resolution
  - CD quality
    - Uniformity
    - Linearity
  - Defect quality
    - **Defect inspection** → This presentation
    - Defect repair
  - etc.

DNP presented new patterning process results for 3x-2x nm node in last EUVL symposium

Year/Production	2003	2010	2011	2012	2013	2014	2015	2016
DR4.0 N pitch (nm) [contacted]	37	45	40	36	32	28	25	26
DR4.0 N pitch CD control (1 sigma) (nm)	34	47	42	37	33	29	26	23
Flash N pitch (nm) (in-contacted pitch)	38	32	28	25	23	20	18	16
MPW/ASOC Mask 1 (4L) N pitch (in-contacted)	24	45	38	32	27	24	21	19
MPW pitch (nm) [open]	47	40	38	36	28	25	22	20
MPW physical pitch (nm) [open]	29	27	24	22	20	18	17	15
Gate CD control (2 sigma) (nm) [4L]	2.0	2.8	2.7	2.7	2.1	1.9	1.7	1.6
Overlap	10.2	9.0	8.0	7.1	6.4	5.7	5.1	4.5
Contact/gate ratio [open]	60	56	41	36	40	21	24	26
<b>Generic Mask Requirements</b>								
Mask magnification [E1]	4	4	4	4	4	4	4	4
Mask nominal image size (nm) [E1]	105	162	141	125	112	100	99	99
Mask minimum primary feature size [E1]	130	114	99	88	78	70	62	55
Image placement (nm, mid-point) [E1]	6.2	5.4	4.8	4.3	3.8	3.4	3.0	2.7
CD均匀性 (nm, 1 sigma) [E1]								
Isolated line (MPU pitch)	4.4	4.0	3.7	3.3	3.0	2.8	2.5	2.3
Deep line (DRAM half pitch)	7.5	6.5	5.8	5.2	4.6	4.1	3.7	3.3
Contact line	1.2	5.0	4.4	4.0	3.5	3.1	2.8	2.5
Linearity (nm) [G]	1.9	6.8	6.1	5.4	4.8	4.3	3.8	3.4
CD error tolerance (nm) [E1]	4.1	3.6	3.2	2.9	2.5	2.3	2.0	1.8
Defect density (nm) [E1]	41	36	32	29	25	23	20	18
Data volume (GB) [E1]	520	655	825	1040	1210	1651	2000	2021
Mask design cost (nm) [E1]	2	2	2	1	1	1	1	0.50
<b>EUV-specific Mask Requirements</b>								
Minimum defect size (nm) [E1]	41	39	37	35	34	32	30	29
Blank defect size (nm) [E2]	41	36	32	29	25	23	20	18
Mask peak reflectivity	>65%	>65%	>65%	>65%	>65%	>65%	>65%	>65%
Peak reflectivity uniformity (% 1 sigma standard)	0.58%	0.47%	0.42%	0.37%	0.33%	0.29%	0.26%	0.23%
Reduced optical working distance (nm 1 sigma) [E1]	0.07	0.06	0.05	0.05	0.05	0.04	0.04	0.04
Absorber sidewall angle tolerance (± degree) [E1]	1	0.75	0.60	0.62	0.5	0.5	0.5	0.5
Absorber LWR (1 sigma) [E1]	5.5	4.8	4.2	3.7	3.3	3.0	2.6	2.4
Mask absolute fitness (nm peak-to-valley) [E1]	39	31	40	41	36	32	29	25



# EUV reticle inspection



# Experimental condition

**Inspection tool: NPI6000EUV $\alpha$  (NFT / Selete)**

- Inspection wave length : 199nm
- Pixel size : 50nm
- Polarization : C pol. /P pol.
- Mode : Die to Die

**EUV blank : HOYA**

- LR-TaBN 70/51nm, CrN 10nm, Si 11nm, Mo/Si 40 pair

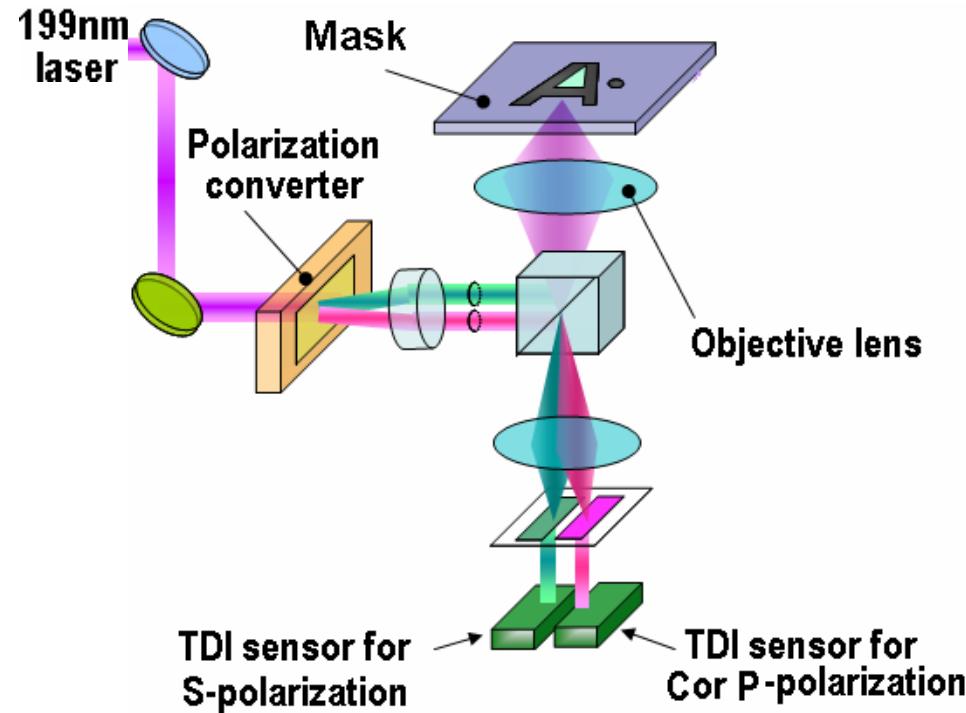
**Others**

- |                         |                                   |
|-------------------------|-----------------------------------|
| ✓ CD-SEM                | : LWM-9000 (Leica)                |
| ✓ DUV reflectivity tool | : MCPD3000                        |
| ✓ Resist patterning     | : P-CAR with 50kV vector EB       |
| ✓ Absorber patterning   | : ICP dry etcher with 2 step etch |

# Inspection tool :NPI6000EUV $\alpha$

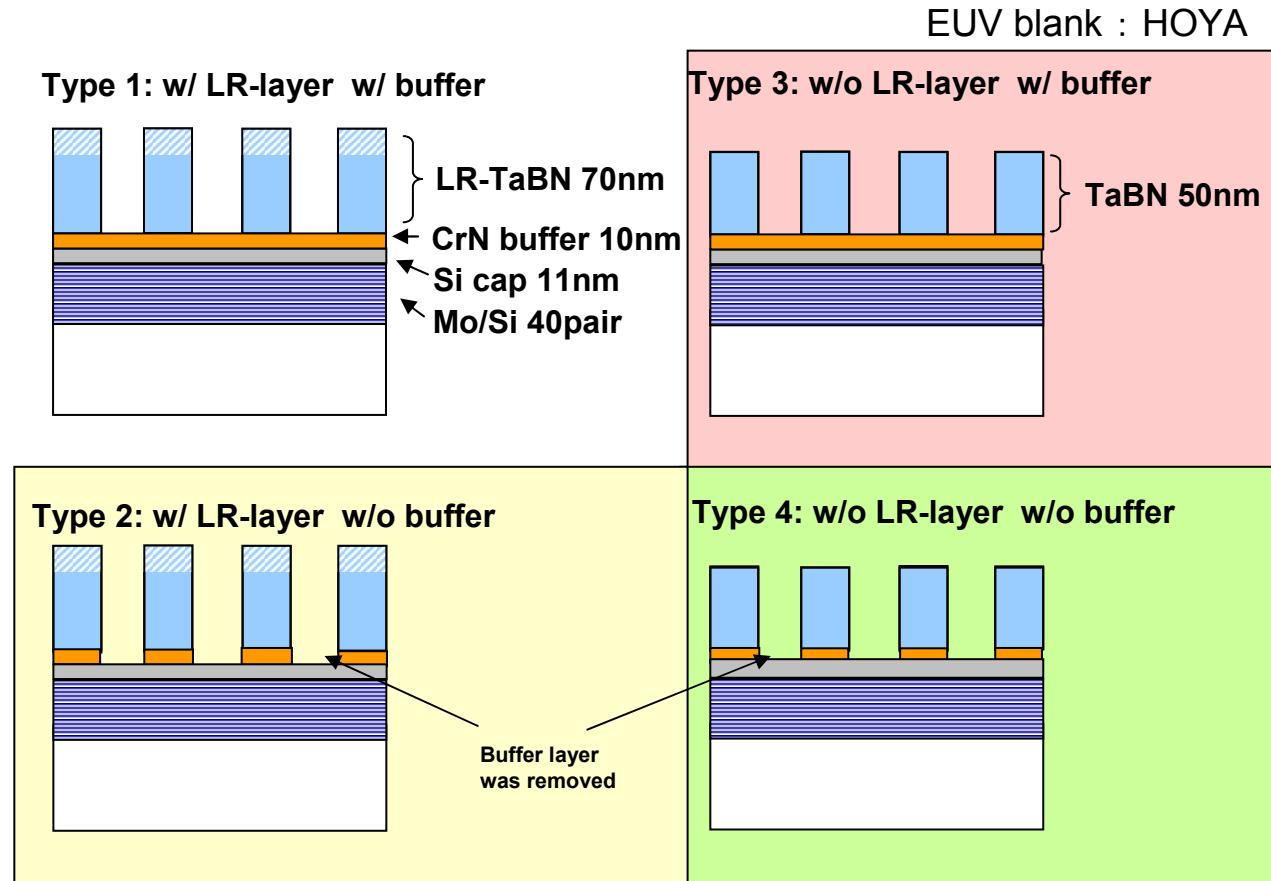


NPI6000EUV $\alpha$



Sensitivities are improved by getting different polarization illumination(P/S/(C) pol.) images at a time and combining each advantages.

# Sample structure

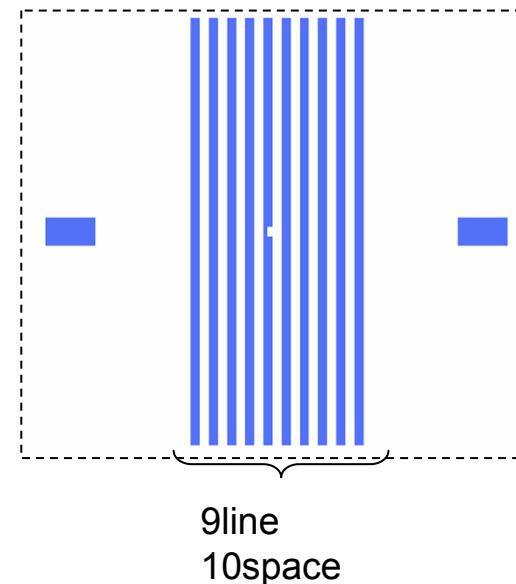


- 4 Different pattern structures were prepared
- Anti-reflective layer of No3 & No4 were removed after absorber patterning

# Sample pattern

Type: Line pattern  
Size(4x): 88,108,128nm

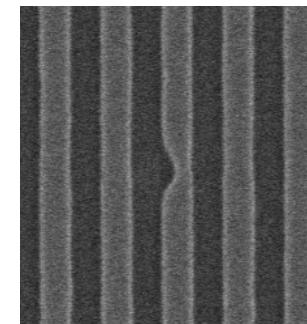
**Line pattern**  
**L:S = 1:1**



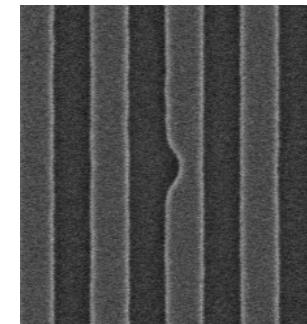
Blue color: etching region  
White color: absorber region

Design defect

clear extension

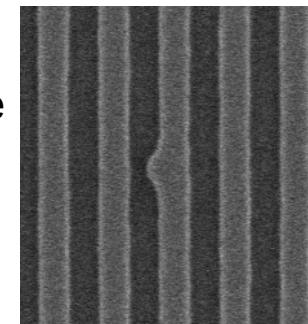


Line size  
88nm

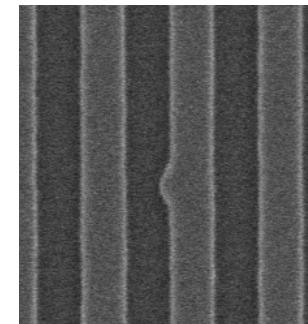
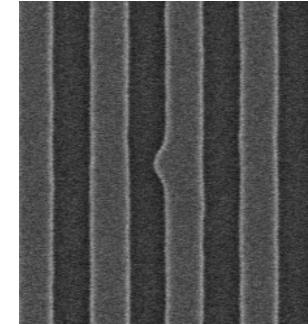


108nm

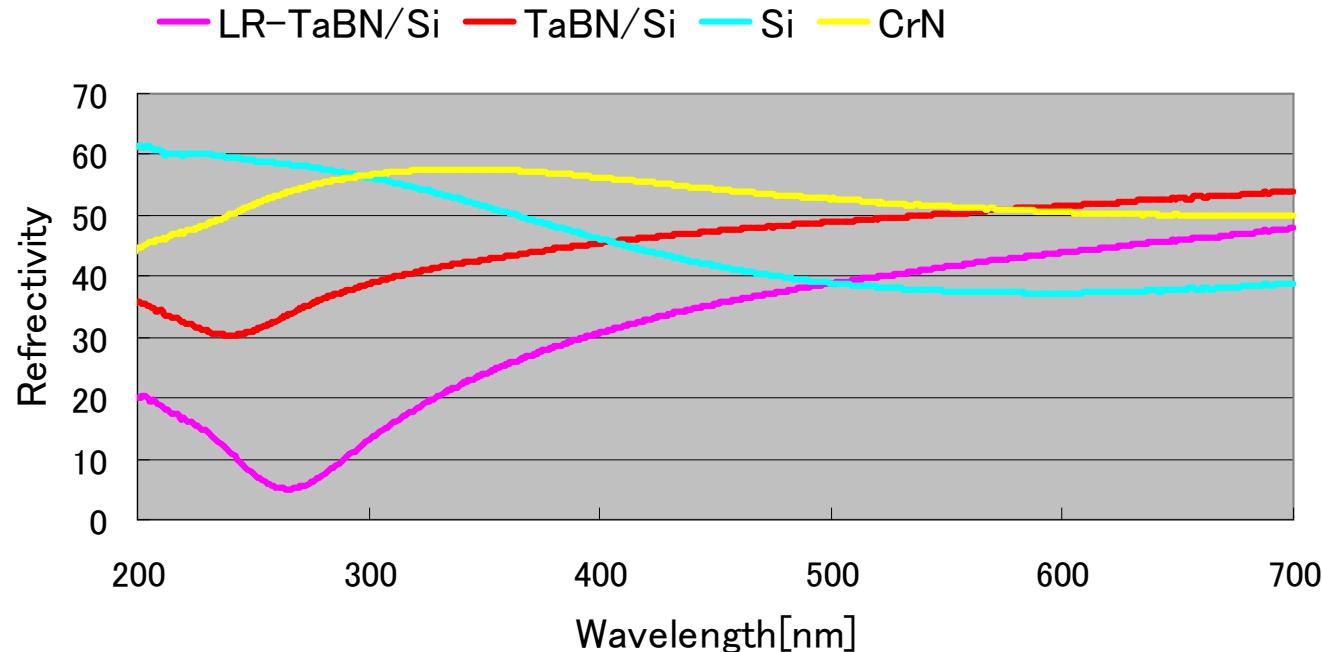
dark extension



128nm



# DUV reflectivity of each material surface



Structure	contrast(@199nm)	absorber thickness
Type1. LR-TaBN - CrN buffer	0.38	70nm
Type2. LR-TaBN - Si cap.	0.51	80nm
Type3. TaBN - CrN buffer	0.11	50nm
Type4. TaBN - Si cap.	0.27	60nm

# Simulation condition

Simulation Tool: "EM-Suite (Panoramic Technology Inc.)"  
/ Thin mask model

Wavelength: 13.5nm

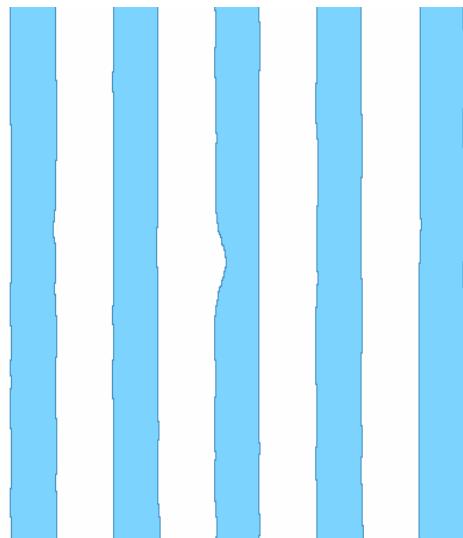
Simulation grid: 1.0nm @mask

Pattern: L/S 32nm hp, 27nm hp or 22nm hp (1x)

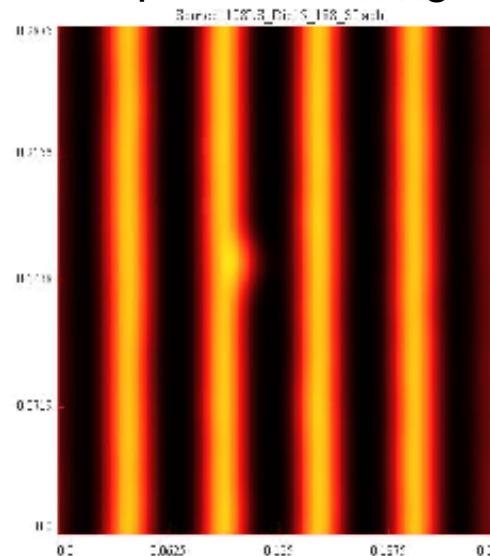
NA: 0.4

Sigma: Conventional 0.5

Input mask image



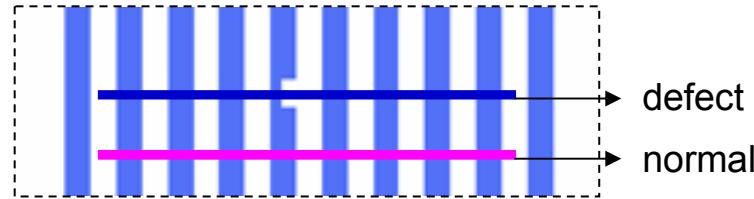
Output aerial image



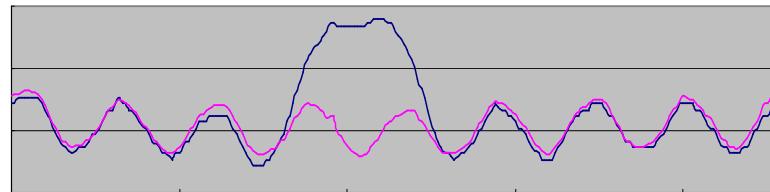
# Comparison of intensity profiles (C pol, LS88nm)

RI-P12

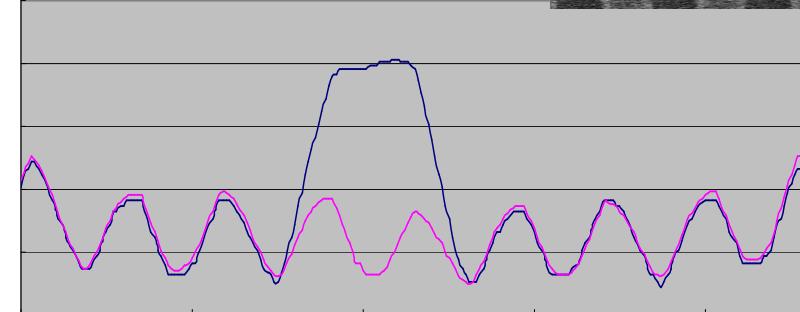
SEM image of PD



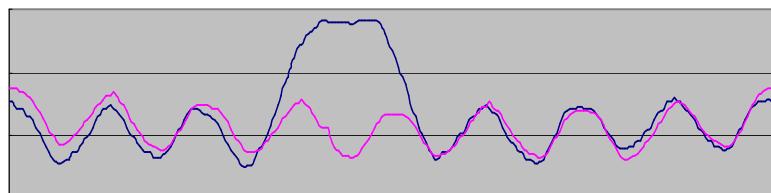
Type 1: w/ LR-layer w/ buffer



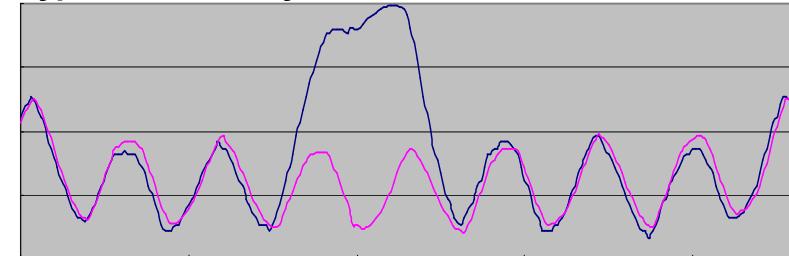
Type 3: w/o LR-layer w/ buffer



Type 2: w/ LR-layer w/o buffer



Type 4: w/o LR-layer w/o buffer

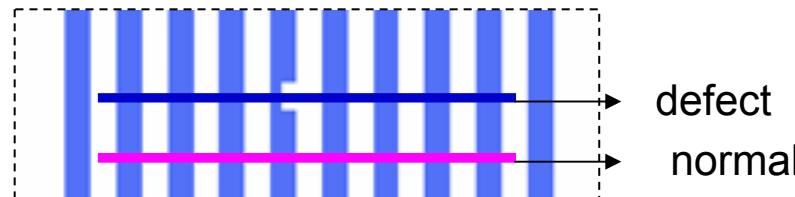
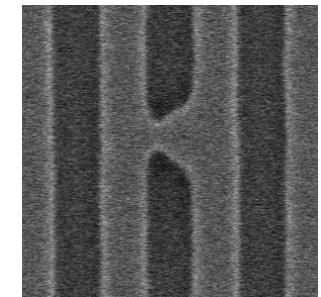


- Contrast of etching area and absorber area is reversed
- Contrast of w/o AR (type3,4) is better than w/ AR(type1,2).
- There is possibility of difference between type3,4 and type1,2 is caused by difference of pattern thickness

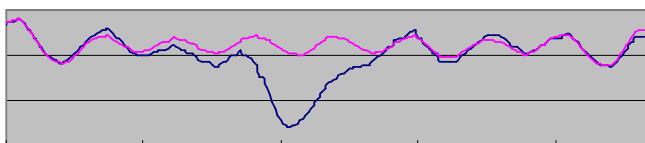
# Comparison of intensity profiles (P pol, LS88nm)

RI-P12

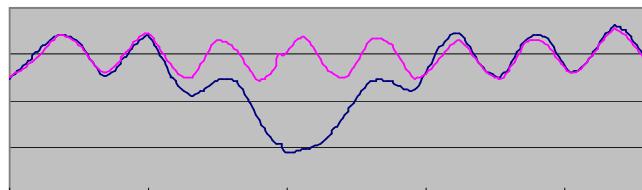
SEM image of PD



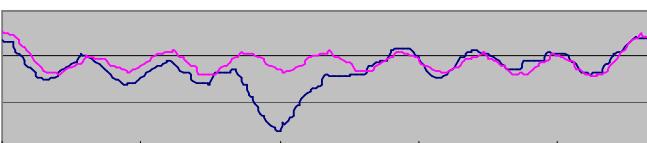
Type 1: w/ AR-layer w/ buffer



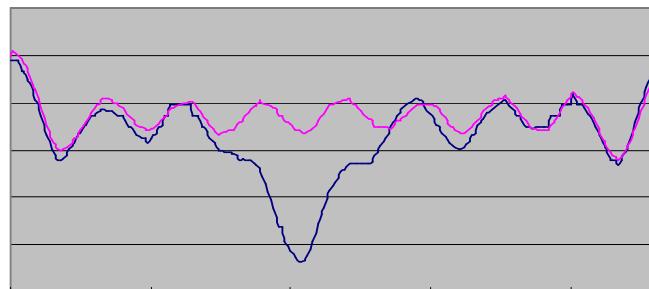
Type 3: w/o AR-layer w/ buffer



Type 2: w/ AR-layer w/o buffer



Type 4: w/o AR-layer w/o buffer



- Optical intensity profile is varied by pattern structure (buffer layer, AR layer)
- Type3 structure (w/o AR and w/ buffer) shows different profile from other.

# Sensitivity of w/o AR structure

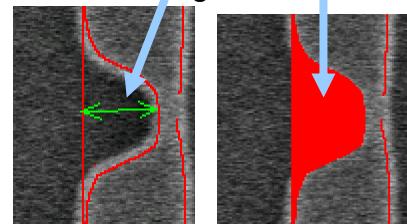
RI-P12

Need to improve  
the sensitivity

Clear extension			dark extension		
size A	size B	w/o buff er	size A	size B	w/o buff er
21	7		20	11	
22	9		24	16	
33	16		34	23	
39	18		39	29	
45	25		45	41	
47	29		50	43	
60	34		62	45	
63	38		88		
70	43		100		
78	58		103		
90			110		
96			116		
100			121		
105			124		
107			128		
112			131		
116			131		
117			134		
123			137		
126			139		
126			142		
128			144		

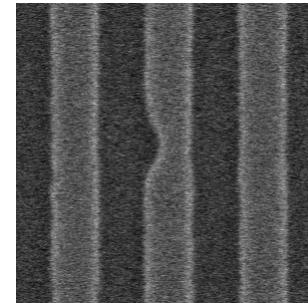
- Line cut or bridge
- >50% detected
- 100% detected
- 10% CD error (simulated)

Size A=square root of defect area  
Size B=defect height

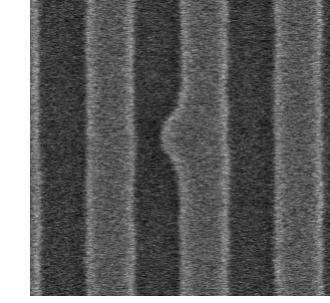


(P pol, LS 88nm)

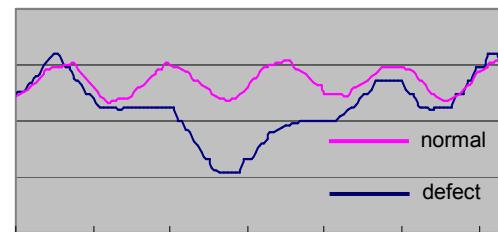
Clear extension sizeA45nm



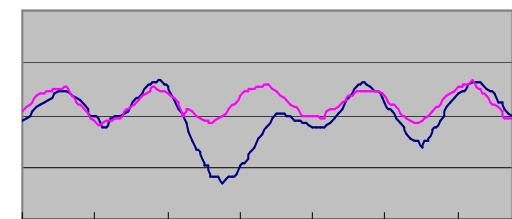
Dark extension sizeA45nm



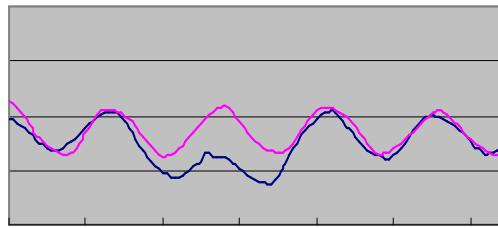
w/o buffer clear extension sizeA45nm



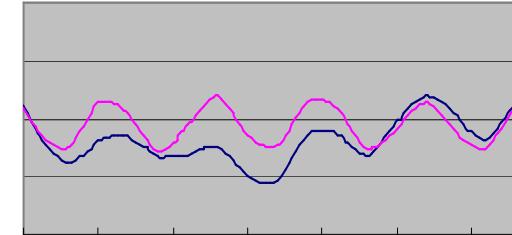
w/o buffer dark extension sizeA45nm



w/ buffer clear extension sizeA45nm



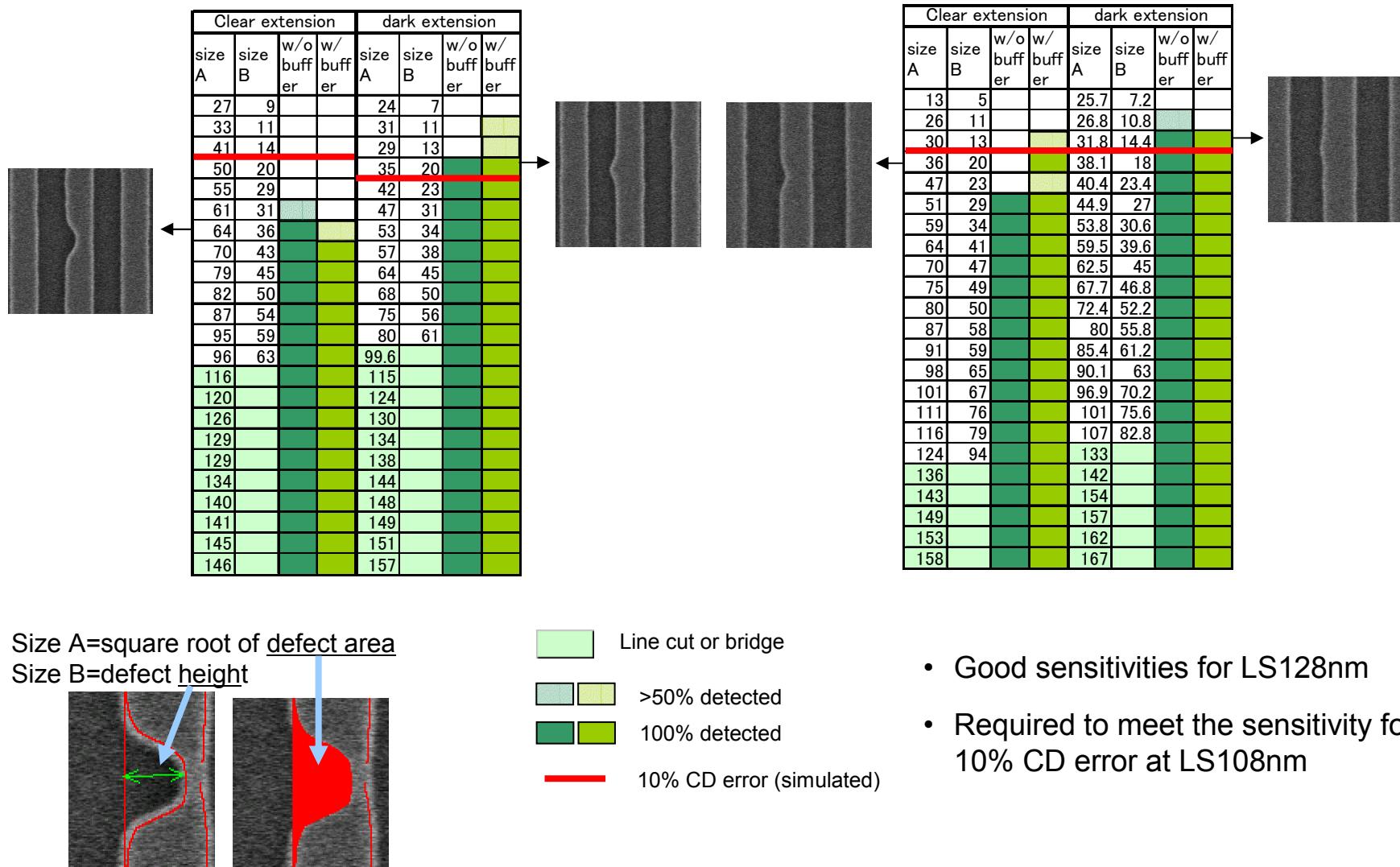
w/ buffer dark extension sizeA45nm



# Sensitivity of w/o AR structure

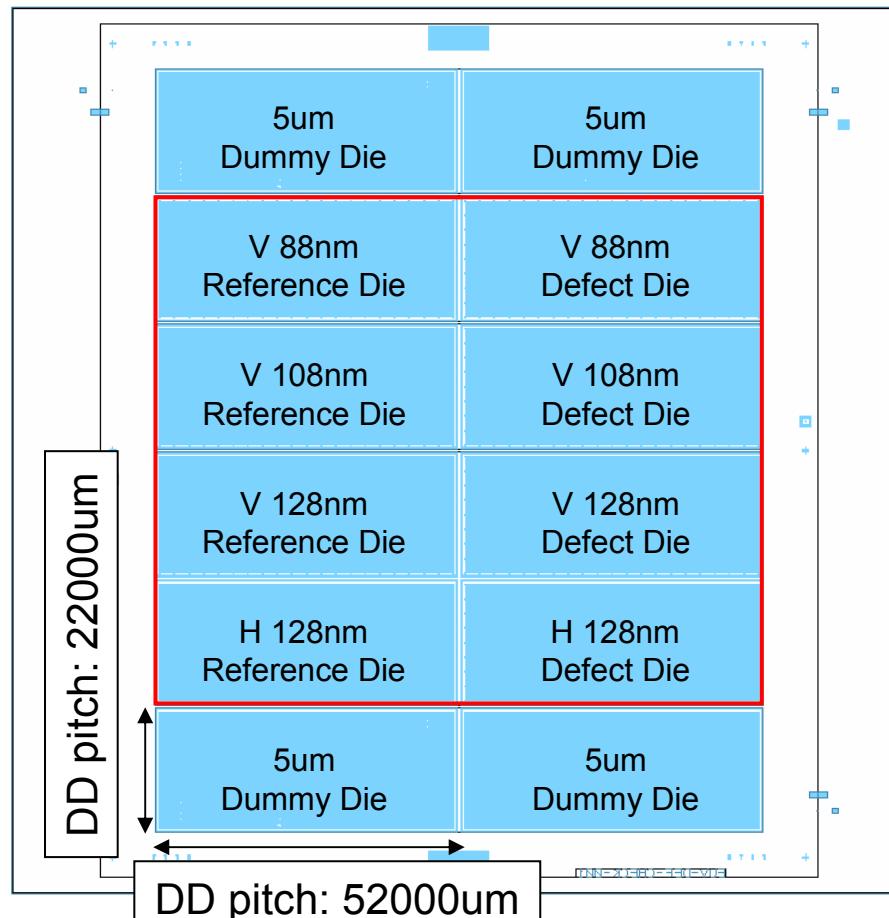
RI-P12

(P pol, LS 108/128nm)



# Example of real defect inspection

## Test pattern



Mask structure:  
LR-TaBN(51nm)/CrN(10nm)/ML40pair  
/6025Qz/CrN-B

Total real defect number. (C pol.+ P pol.)  
(After double count and nuisance defect removed)

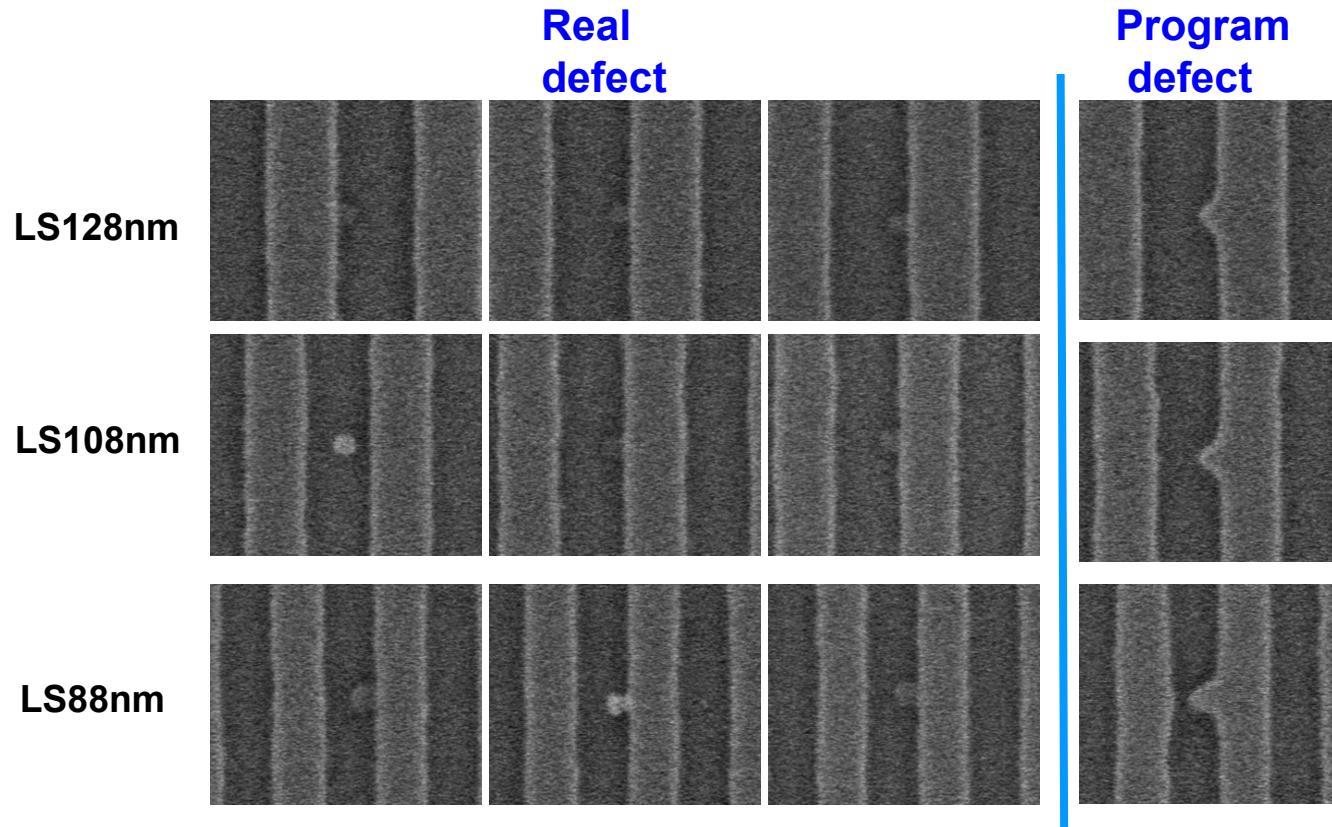
V88nm : 54  
V108nm : 92  
V128nm : 110  
H128nm : 91

Many of defects are small size defect <50-60nm

# Example of real defect SEM image

RI-P12

Minimum size of real / program defect detected by NPI6000 P pol.



**Small real defects were detected !**

## Summary

- We evaluated the EUV mask defect inspection by using NPI DUV mask inspection tool.
  - ✓ P pol. illumination optics showed excellent performance for hp32nm LS pattern and inspection possibility for hp27/22nm node.
  - ✓ It is necessary to optimize many parts of DUV tool and mask structure for w/o AR layer structure, because the intensity profile of w/o AR layer structure show complicated behavior.

## Acknowledgement

- NPI6000EUV $\alpha$  tool development work was supported by NEDO
- NuFlare Technology Inc. for NPI 6000EUV $\alpha$  operation